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COAL GEOLOGY: AN OPPORTUNITY FOR RESEARCH AND STUDY

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ABSTRACT.

Coal Geology is conveniently divided into two fields, one which concerns the geology of coal beds, the other the geology of coal itself. In the first field study and research have to do with coal resource and related activities, with mining geology, with the natural history of coal beds; in the second field study is concerned with the botanical, petrographic, and chemical constitution of coal. It is particularly desirable that chemical studies be related to the geological factors that produced coal from precoal material and the subsequent metamorphism of coal. Systematic geological training, instruction, and research in all these branches of coal geology have been much neglected in the academic field.

INTRODUCTION.

The nature of research in the geology of mineral substances varies among these substances. Conventional geological considerations are of prime importance, and research bearing on these considerations provides the fundamental knowledge that facilitates the discovery and recovery of ore deposits and water and oil resources.

With respect to coal the case is different. The problems of coal occurrence and distribution are solved by careful stratigraphic and mapping methods. Somewhat more exacting are those geological problems involved in the achievement of safe and easy recovery of the coal.

But beyond all considerations involving occurrence, supply, and recovery of the coal resources is the fundamental geological problem of the character of the coal material itself, the solution of which is essential to the satisfactory classification and description and the effective and complete utilization of our coal resources. To achieve this understanding the geological factors that effect diagenesis, incoalation, coal metamorphism, and coal classification must be recognized and evaluated, the nature of the chemical changes resulting from the varying geological influences must be specifically determined, and the variations in chemical constitution and physical attributes must be correlated.

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NATURE OF COAL RESEARCH.

This article reviews the general field of coal geology and points out some of the possibilities for geological research, particularly of a basic or fundamental character, that exist in this field.

Coal geology may be conveniently partitioned into those fields of knowledge and inquiry that concern the geology of coal beds and those that concern the geology of the coal material itself. The geology of coal beds consists of knowledge relating to the discovery and delineation of coal resources, the stratigraphic and structural conditions, and the geologic and economic conditions that affect the mining operation. The geology of coal material, on the other hand, consists of knowledge relating to the nature and origin of its physical heterogeneity in composition and properties, of its variations in chemical composition and properties, and of those geological conditions whereby these several variations were produced. These various topical sections of coal geology are discussed briefly.

COAL RESOURCES STUDIES AND ACTIVITIES.

Coal resource inventories require careful and detailed stratigraphic studies and mapping by technically trained geologists. The detailed stratigraphic succession of few, if any, of our American coal fields is thoroughly understood, thereby denying us complete understanding of the conditions of coal bed occurrence and origin. Furthermore, at many localities faulting and folding of the coal measures make necessary the skillful use of stratigraphic methods for the identification of coal beds. The growing usefulness of fossil spores obtained from coal beds by maceration methods is beginning to give the coal beds importance in their own right as stratigraphic key beds.

The mapping of coal resources commonly provides data for the construction of structure maps on one or more coal beds. Such maps have proved helpful not only for indicating the position and distribution of a particular coal bed, but also for indicating the nature and potency of the geological vicissitudes to which the coal beds have been subjected. They also provide a plane of stratigraphic reference, and in oil and gas regions they may indicate the position of structures favorable for the accumulation of oil and gas.

Of much importance in fundamental studies is the information concerning the characteristics of coal beds and the relationship of coal beds to their associated strata; these data have been largely supplied by field geologists engaged in coal resource studies. Discriminating and accurate description of coal beds as observed in the field are essential to a thorough understanding of coal bed deposition and coal metamorphism. It would be a serious mistake to assume that all variations in coal bed characteristics are known and catalogued so long as large bodies of coal have not been carefully described.

COAL-MINING GEOLOGY STUDIES.

Successful coal recovery requires an understanding of the characteristics of the strata above and below the coal bed being exploited. This is a phase of geology much neglected and too lightly regarded in academic geology curricula. Nor is this field of geology adequately supported by observational and experimental data. Geologists engaged in coal resource inventories are commonly unfamiliar with the behavior of different types of roof and floor materials in the mining process and hence are unable to evaluate a particular coal deposit either from the character of outcropping associated beds or from diamond drill cores, in the light of prevailing mining practice. Consequently, opinion is commonly divided between geologists and practical mining people as to the economic value of a coal reserve.

There is also an almost complete lack of experimentally established data on the strength of rocks such as commonly compose the coal measures in various coal fields of this country. This lack of knowledge includes uncertainty as to the extent to which the various accordant or discordant stratigraphic relationships of successive strata of different lithologic composition affect the strength of the sedimentary mass associated with the coal beds. Nor, as previously stated, do geologists usually possess a knowledge of the conventional mining methods used in supporting rocks of various strengths and solidity.

The studies which must eventually be made to determine the forces that cause mine roof and floor failures will probably provide information about the nature and degree of the forces that cause the metamorphism of coal.

THE NATURAL HISTORY OF COAL BEDS.

The natural history of coal beds, particularly as concerns their origin, has occupied the attention of geologists almost from the beginning of the science. Coal geology would be incomplete without consideration of the origin of coal beds, the nature of the plants that contributed to the coal beds of various ages, the story of the events and conditions that favored plant growth, the preservation of plant débris in various degrees, and its burial and alteration to coal These are geological processes effective as soon as the plant substance becomes incorporated in the coal swamp débris, with biological agencies effective to a greater or lesser degree until burial is accomplished and possibly for some time thereafter. An understanding of the natural history of a coal bed requires knowledge of the sedimentary conditions of the various strata associated with the coal beds and of the various biological and geological factors that effect plant disintegration on the one hand, and preservation, burial, and geological maturation on the other. It is desirable for early achievement of important and comprehensive results that the problem of coal bed origin be definitely correlated with problems related to coalification in general to avoid irrelevant investigations. Among the numerous problems concerning coal bed origin which have a bearing on the general problem of coal constitution are the following:

1. Natural history of underclays and their significance as soils.
2. Origin of coal beds of different type: Cannel, algal, bright banded, and splint coals.
3. Nature and origin of laminations and banding in coal beds.

4. Time involved in coal bed accumulation and in coal bed formation (incoalation).
5. Original thickness of coal beds.
6. Sedimentary equivalent of coal beds.
7. Origin of isolated shale lenses in coal beds.
8. Effect of the lithology of superimposed sediments upon the kind and rate of coalification.
9. Origin and development of cleat and cleavage.
10. Time and nature of mineral infiltration of calcite, kaolinite, and pyrite.
11. Origin and occurrence of pyrite (and marcasite) in coal beds.
12. Geological rôle of soluble humic acids found in peat waters.

COAL CONSTITUTION STUDIES.

Closely related to the natural history of coal beds are studies in the constitution of coal that have been carried out in the field of coal botany, coal petrography, and coal chemistry. Such investigations have to do with the coal material and attempt to determine the physical properties and chemical and physical make-up of the coal. These studies are more fundamental than those listed under previous sections only in the sense that they are primarily concerned with coal itself.

Studies in the Botanical Constitution of Coal.—From a botanical point of view coal is an aggregate of fossil plant material of which the components are individually more or less recoverable and identifiable as discrete organic entities or structures. It is thus possible to resolve coal into various categories of plant parts or phyterals without attempting rigid botanical classification. Thus the coalified woody material, other than fusain, but including bark, has been grouped under the general category of *anthraxylon* (13, 15).[2] The non-woody material, on the other hand, which is largely finely fragmentary is all classified as attritus. But within attritus, in the thin sections of some coals, it is possible with the aid of the microscope to differentiate a variety of fossil entities representing spores, sporangia, waxes, resins, cuticles, and other minute organic structures as well as minute fragments of humic or woody matter.

The possibilities of botanical research of various kinds in connection with the material present in beds are extensive. For example, recently the usefulness of spores as index fossils in the coal measures of Illinois has been explored (2) with promising results. Other resistant plant parts, such as cuticles, may have a similar stratigraphic use, but they are in general inherently less promising than spores.

In some coal beds coal-balls are relatively common (5, 6) and these provide many well-preserved plant fossils representing the same kinds of plants that compose the coal beds but in uncompressed or only slightly compressed condition, so that the detailed structure of the coal-making plants can be readily discovered. Considerable quantities of such material have been col-

[2] Numbers in parentheses refer to Bibliography at end of paper.

lected in Illinois, Indiana, and Iowa and are now available for study at various universities.

Botanical constitution of coal has for some time been regarded favorably as the key to and basis of variations in coal type, hence as of fundamental importance in determining the specific characteristics of coal as indicated by variations in physical properties, chemical composition, and in combustion, carbonization, and other behavior characteristics. Evidence seems to indicate that the rate and process of incoalation (coal formation) varies among the different classes of botanical substance contributing to the coal bed (9).

Chemical studies (17) indicate that there are chemical differences between the humic and waxy substances in individual coal beds, at least in coals of relatively low rank.

The importance of botanical research in coal is such as to merit the attention of a few geologists with botanical training or botanists with geological training. It is desirable to know all that can be learned of the botanical composition of coal. Only as the possibilities of variation in coal arising from variation in botanical constitution are realized can the effect of geological influences in coal formation and coal metamorphism be evaluated. Certain studies in the chemical constitution of coal may require much closer correlation with botanical data than has been generally achieved.

Petrographic Constitution of Coal.—Coal petrography, as it is commonly understood, consists of little more than a description and classification of coal material in terms of what Stopes (11) designated the four banded ingredients.

The original definitions of the banded ingredients were based upon megascopic criteria and the gross aspects of banded bituminous coal. Subsequently the definitions were modified, in line with certain megascopic considerations, until the Stopes system of coal petrography has become inextricably involved with microscopic and botanical qualifications that detract considerably from its usefulness or at least complicate its application.

The petrographic system of coal description has been further complicated by the superimposition of a quasi-mineralogical framework upon the original simple megascopic subdivision (12). This development follows from the desire to regard the coal ingredients as rock types each of which is composed of a characteristic mineral component just as igneous rock types are composed of characteristic minerals. These hypothetical pseudo-mineralogical substances have been designated by the term maceral (12). The maceral concept has been widely adopted for descriptive purposes, especially by European coal geologists. Since these so-called "mineral" substances are obviously organic entities or fragments of such entities, it was suggested by the writer (1) that the term phyteral, as a general name for such plant entities in coal, was preferable to maceral for designating coal components identifiable only as a plant entity. The composition of the phyteral is implied by its identity. The term maceral actually does no more than this although there is the implication that it does more. Unfortunately the introduction of this botanical term has not displaced the use of the term maceral, and we find phyterals grotesquely described as consisting of a particular maceral, an entirely unnecessary and redundant elaboration.

Fusain.—Among the petrographic banded ingredients fusain is an important and conspicuous element. Those workers who base their determination on botanical considerations also recognize the presence of fusain (16), so that fusain, as well as anthraxylon and attritus, is regarded as one of the components of banded coal. It is regarded, however, not as a botanical component, but as a petrographic unit. The botanical categories set up by Thiessen were accordingly burdened with a component describable only in petrographic terms. Fusain was adopted by Stopes as one of the four petrographic ingredients and the terminology proposed by Stopes conforms in general to that previously employed by the French (11, p. 472).

Fusain exists in beds, lenses, aggregates in various form, and of particles greatly varying in size and degree of dissemination, down to those of microscopic dimensions. It is possible that the so-called opaque matter of Thiessen (14) characteristic of splint coals or durain may consist of finely divided fusain. This material has been designated by the maceral name micrinite, whereas the maceral composing fusain is called fusinite. The weakness of the maceral concept is revealed in the uncertainty as to the character of either micrinite or fusinite as hypothetical substances, so that it is impossible to differentiate them.

Petrographic Method of Coal Description.—Petrographic concepts have been regarded as less fundamental for purposes of coal description and classification than concepts based upon microscopic and botanical considerations. Nevertheless, the petrographic method of coal description, even in its present unsatisfactory technical status, owing to inexact and incomplete definition, has considerable usefulness as a tool of coal research in defining the physical characteristics of coal. The megascopic distinctions between different ingredients of the coal bed are valid, provided certain arbitrary, clearly defined standards of differentiation are observed. Detailed petrographic profiles of a coal bed in terms of the banded ingredients are useful in appraising its amenability to various preparation practices or to selective mining, in order to maintain a uniform product. It is particularly desirable to have such profiles prepared from cores when a virgin coal field is being explored. It is believed that they have an importance comparable to that of chemical analyses of such cores. Unfortunately drilling practice too often does not provide the skill necessary to obtain cores of the quality necessary for the preparation of such profiles.

Petrographic analyses (7) or assays of broken coal are essential when coal is to be used for hydrogenation, since the highly carbonized material—fusain and opaque matter—detracts from the usefulness of coal for hydrogenation purposes. Actually far too few such assays have been made to permit positive conclusions as to their general value, or even to be certain as to the ultimate usefulness of the distinctions applied.

CHEMICAL CONSTITUTION OF COAL.

Elementary Analysis.—The oldest and simplest method of determining the composition of coal was by means of the elementary or ultimate analysis. In general this form of analysis provides, by direct determination, values for the amount of hydrogen and carbon in the combustible material composing coal, oxygen being a residue, the amount of which is determined by difference and therefore values for oxygen are somewhat less accurate. Differences in the combustible portion of coal, that is the mineral matter-and-moisture-free coal arise chiefly from variations in oxygen content, the amount of oxygen decreasing progressively with increase in rank. This generalization may not apply to coals beyond the bituminous rank. Differences among coals may also exist because of variations in the quantity of waxy and resinous material present, but the nature and extent of these differences are not well known. Similarly variation in the quantity of fusain present undoubtedly affects the elementary composition.

There is apparently a change in the relationship of carbon and hydrogen as coal advances from bituminous to anthracite rank, so that it is probable that anthracite and bituminous coal should be compared on some basis fundamentally different from that upon which comparison of two common types of bituminous coal is made. These relationships require investigation.

Commercial Type of Analysis.—To meet commercial requirements there has been developed what is known as the "proximate" method of coal analysis. The proximate analysis when accompanied by determinations of sulphur content and of calorific value provides the standard criteria for differentiating coals of various ranks by the application of certain empirical rules. Such distinction is based upon samples representing the whole bed collected under standard conditions. Rank, therefore, represents an average, and since most coals consist predominantly of humic material, the rank of the anthraxylon composing the vitrain and clarain present in the coal bed very largely determines the rank of common banded coal.

Chemical studies of the components of coal, the banded ingredients and the botanical entities (phyterals), using the methods of the ultimate and proximate analysis, although not neglected have not been adequate for providing a basis for sound judgment in regard to differences among the components. In general but slight differences have been discovered between bands of very bright coal, that is either vitrain or bright, highly anthraxylous clarain, and the duller portions of the coal consisting of grayish clarain and durain (8). Fusain may be definitely differentiated from the other banded ingredients in bituminous coals by its high carbon or fixed carbon content.

In comparing analyses of banded ingredients uncertainty usually exists concerning the degree of discrimination used in the selection of samples for analysis. This is particularly true when analyses are selected from a wide variety of sources representing samples collected by many persons in widely separated times and places. It still remains to be determined whether or not even the proximate and ultimate forms of analysis might not reveal consistent and significant differences between varieties of coal selected to represent actual differences in the botanical or phyteral composition. This is a desirable field of investigation.

With respect to the phyterals—differences are discoverable between humic and waxy phyterals, that is, between vitrain or anthraxylon and waxy spore exines (10, p. 417), but it is suspected that such differences tend to disappear in coals of high rank (9).

In general, however, except for fusain in the middle and low rank varieties of coal, it may be that the data provided by ultimate and proximate analyses, and particularly by the latter, are not sufficiently specific in regard to chemical composition to permit differentiation of the various banded ingredients and of the phyterals found in coal (3, pp. 383–4).

Organic Analysis.—The conventional methods of organic analysis have also been applied to coal to a rather limited extent. The usual procedure of analysis involves investigation of samples collected by standard methods of face sampling. Hence the sample, when the common banded type of coal is used, represents an average of a variety of organically different substances or phyterals. Therefore the material analyzed is chemically complex, not only because of the complexity of the composition of the individual phyteral, but because a considerable number of such units are inextricably intermingled almost as in a liquid solution. Since most banded coal is predominantly humic in origin, the prevailing results will be very similar whatever coals were used, except for differences that might spring from variations in rank. It is not to be expected that the coal petrographer and coal botanist will be entirely satisfied with results obtained from analyses of such samples.

Such analytical examination as has been made of the banded ingredients and to a much less extent of the individual plant components or phyterals indicates that the organic substances that survive the diagenetic processes and form coal consist of aromatic compounds (4). This appears to be true whether the coal is composed of humic substances (anthraxylon or vitrain), waxy phyterals (spore, exines, cuticles, etc.) or fusain. Fusain displays distinctive characteristics that makes chemical differentiation possible, at least in the middle and low rank coals. Yet these differences are small and it is pointed out that they are none other than those indicated by elementary analysis (3).

In general it appears that the organic chemists regard physical variations in coal resulting from difference in phyteral composition as not necessarily chemically significant. "Differences in appearance of the bands of any given coal are not adequate criteria for differences in chemical composition. Although these differences in appearance may be associated with differences in chemical composition, both the amount and the direction of the differences must be determined by chemical means in each case" (3, p. 384).

In line with the conventional methods of analysis of organic compounds, the composition of coal has been investigated by halogenation, oxidation, reduction (hydrogenation), and by hydrolytic reactions, in general, using gross samples of coal rather than specific ingredients or phyterals.

The various methods of analysis lead to the same general conclusions in regard to the aromatic nature of the coal material. Differences in these compounds appear to parallel progressive change in coal from rank to rank. It does not yet appear that rank can be definitely identified by the state of condensation of the aromatic molecule, although it seems to a geologist that this possibility exists. Nor does it seem to be certain whether the overwhelming predominance of the aromatic compound in coal is a result of the incoalation and coalification processes, or simply an inheritance of pre-coal conditions of the plant débris.

In closing this section it may be pointed out that the main efforts of coal chemists have been directed not toward discovering the fundamental chemical differences in the materials composing the "coal conglomerate," but rather toward the determination of the nature of substances derived from coal when it is subjected to thermal decomposition. It seems quite possible that the almost unlimited variety of materials present, at least potentially, in the liquid by-products of coke manufacture is partly responsible for the idea that the coal material itself is equally complex and varied, whereas complexity and variety in the by-products may be the result of the highly complex physical conditions accompanying heat treatment.

It is desirable to know more accurately the character of the initial source of these by-products and the extent to which the final complexity is the result of either initial complexity or physical heterogeneity. Such knowledge might also provide an answer to the unsolved problem of the cause of the coking phenomenon.

FUNDAMENTAL GEOLOGICAL RESEARCH INTO COAL CONSTITUTION.

The position of geology as an applied science has been so frequently and emphatically reiterated that it has come to be an accepted belief that for fundamentals the geologist must turn to the biologist, chemist, physicist, or mathematician for the correct solution of even geological problems, and that geology possesses no fundamental concepts in its own right. Even among geologists there is a common idea that fundamental research in coal must be carried on in the fields of botany, chemistry, or physics, irrespective of geological considerations. Such a conclusion reveals a failure to understand the importance of the coordinating and correlating function of geology.

May not research in coal in the biological and chemical fields in general have failed to reach the desired objective of an understanding of the nature and constitution of coal largely because basic geological factors have been neglected? Geological considerations would seem to be of fundamental importance in any basic research in coal material because coal is a product of geological process of a fairly definite general character.

Among these geological processes are certain important ones which experience, based upon wide investigation and careful observation of natural phenomena and intelligent deductions, has associated with the metamorphic process. Metamorphism is a basic geological concept; the process is described, defined, and identified by geological criteria. It is doubtful whether the general concept of metamorphism can be adequately defined in strictly chemical or physical terms, although explanation of the process can be made only in terms of physics and chemistry employed as the tools of geology.

The existence and patterns of numerous other geological phenomena have also been established by the geological methods of naturalistic interpretation of the physical environment and events. Explanations are rightly sought through use of biological, chemical, and physical sciences and mathematics, but geologists should regard basic research in the fundamental nature of coal material as concerned primarily with a natural substance owing its existence and specific character to geological conditions. These conditions by reason of their progressive increase in severity produce coal from pre-coal material and subsequently alter coal through successive stages of increasing rank and ultimately change it to graphite. Geological processes bring about the chemical changes of coal formation and coal metamorphism and geologists should seek to determine both the nature of the geological influences that operate to change the organic materials and the reason for the specific changes produced.

Studies in coal resources and other studies relating to the physical and chemical constitution of coal such as have been suggested are essential preliminaries to fundamental coal research. Much more work along these lines needs to be done. Likewise the botanists have probed very closely to those vital considerations of basic research and the knowledge thus gained will contribute to the ultimate understanding of the fundamental constitution of coal. Such work needs to be continued.

The conclusions reached by the organic chemist, through conventional analytical procedure, tend to focus attention upon the failure of such investigations to discover chemical reality in physical differences recognized by the coal petrographer and coal botanist. The geologist should not, however, be satisfied with such conclusions unless they are based upon coal samples selected by specially trained coal geologists to illustrate specific varieties of coal material. Furthermore, the relation of chemical variations in coal material should be related more specifically to the kind and degree of geological forces that produce rank variations in different kinds of coal material. In general a more substantial and easily traveled bridge must be laid between geological and chemical concepts relating to coal before complete correlation of ideas is possible. It is important that the geologists on their part explain more clearly the nature of the geological factors that have been involved in the formation and metamorphism of coal and that the chemists understand the nature and importance of geological processes in bringing about these changes, in other words to regard coal as a dynamic substance.

CONCLUSION.

A basis exists for more systematic education and training in the field of coal geology. Coal geology elucidated by suitably trained personnel provides a discipline as rigorous as that provided by other but more conventional fields of academic study and research. It has the superior value of being directly concerned with a material of prime importance in our industrial civilization, and one whose importance increases as petroleum supplies decline. Special attention is called to the need for basic research in coal, thereby providing a foundation for general academic activities in this field. Without such basic research no substantial achievement in the academic field of coal geology can be expected. It would appear, therefore, that any educational institution contemplating the establishment of courses in coal geology should support such plans by setting up a well organized program of basic research in coal.

Basic geological research in coal should explore the nature of the coal material as a substance fundamentally geological both in its origin and subsequent history. Although differences among coals can be described to a certain extent in physical terms, it is generally true that unless differences can be described in chemical terms their actuality is open to serious doubt. In order to achieve significant results the geological research, although carried on from a geological point of view, must seek for expression of the geological processes and materials in chemical terms. Undoubtedly this will require close cooperation between geologists and chemists, and the availability of chemists with an understanding and appreciation of geological philosophy.

It would be very unfortunate indeed if the suggestions that have been made should be interpreted as indicating that the geological approach provides a short cut to an understanding of the chemical constitution of coal and a bypassing of the methods of analytical chemistry. The significant aspect of the proposal is that the chemical investigations should be carried on in such a way that the geological factors that produced the various types and ranks of coal become a part of the chemical concepts. First, the nature of the geological factors will have to be determined, analyzed, and evaluated as to their probable influence on the chemical structure of coal. Whether or not this naturalistic geological approach to the problem can contribute any assistance to the solution of the central problem of the constitution of coal remains to be determined, but it seems probable that a well-trained capable geologist with adequate assistance in three or four years of undivided attention to the problem would be able to discover and define the main geological factors involved in the formation and metamorphism and geochemistry of coal. An entirely new approach to the study of the fundamental constitution of coal might result.

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